

**ON THE QUANTITY AND QUALITY OF KNOWLEDGE**  
**THE IMPACT OF OPENNESS AND FOREIGN RESEARCH**  
**AND DEVELOPMENT ON NORTH-NORTH AND**  
**NORTH-SOUTH TECHNOLOGY SPILLOVERS\***

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**Abstract**

Knowledge accumulation means either new knowledge (an increase in its *quality*), greater access to existing knowledge (an increase in its *quantity*), or both. This paper examines the relative contribution of these two components of knowledge to TFP for North-North and North-South trade-related knowledge diffusion, with quantity proxied by openness and quality by the R&D content of trade. The measure of foreign R&D used in the literature on trade-related knowledge diffusion imposes equal contributions to TFP of openness and of R&D content of trade. Our analysis shows that R&D has a greater impact on TFP than openness for North-North trade and, conversely, openness has a greater impact on TFP than R&D for North-South trade. These results imply that the impact of openness on TFP in developing (developed) countries is larger (smaller) than previously obtained in this literature, and that developing countries can obtain larger productivity gains from trade liberalization than previously thought.

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## Non-Technical Summary

A number of studies have examined the impact of international trade on technology diffusion among trading partners. The studies that followed the approach initiated by Coe and Helpman (1995) have estimated the impact of “foreign R&D” on a country’s total factor productivity (TFP). A country’s index of foreign R&D is built by multiplying the R&D stocks of its trading partners by the level of imports from each partner (with the imports divided either by the level of the country’s total imports or by its GDP for estimation at the aggregate country level, and by the level of the industry’s value added for estimation at the industry level). This formulation implicitly assumes that trading partners’ R&D stocks and the level of the country’s imports enter the estimated equation symmetrically. However, this need not be the case, as is shown in this paper.

Knowledge accumulation means either new knowledge (an increase in its *quality*), greater access to existing knowledge (an increase in its *quantity*), or both. This paper examines the relative contribution of these two components of knowledge to TFP for North-North and North-South trade-related knowledge diffusion, with quantity proxied by openness and quality by the R&D content of trade. The measure of foreign R&D used in the literature on trade-related knowledge diffusion imposes equal contributions to TFP of openness and of the R&D content of trade. Our analysis shows that R&D has a greater impact on TFP than openness for North-North trade and, conversely, openness has a greater impact on TFP than R&D for North-South trade.

The paper provides explanations for the difference in results between North-North and North-South trade. The results imply that the impact of openness on TFP in developing countries is larger than previously obtained in this literature and that these countries can obtain larger productivity gains from trade liberalization than previously thought. The opposite holds for developed countries.

# **ON THE QUANTITY AND QUALITY OF KNOWLEDGE: THE IMPACT OF OPENNESS AND FOREIGN RESEARCH AND DEVELOPMENT IN NORTH-NORTH AND NORTH-SOUTH TECHNOLOGY SPILLOVERS**

## **1. Introduction**

The theory of endogenous growth based on increasing returns to knowledge accumulation originated with Romer (1986, 1990). One of the implications of this theory is that policies affecting knowledge accumulation can have a permanent effect on the rate of economic growth.

Knowledge is assumed to differ in two ways from traditional inputs. First, it has public good characteristics; and second, new knowledge is complementary to existing knowledge so that the marginal product of additional units of knowledge increases. For instance, a new idea that is generally available raises productivity and increases market size, and this raises the return to additional ideas. And a high-knowledge economy is likely to be able to make productive use of an advanced piece of knowledge, while a knowledge-scarce economy might not.

The assumption that knowledge is a public good means that, once generated, it diffuses costlessly and is available to the entire economy. Though knowledge clearly possesses public goods characteristics, most knowledge is privately produced and is rarely a *pure* public good whose diffusion is instantaneous or free. Much new knowledge is embedded in new products or in improved qualities of existing products and does not diffuse either freely or instantaneously. This is especially true for international knowledge diffusion where additional barriers exist, including tariffs and quantitative restrictions on imports, different standards and regulations, and higher communication costs (including those related to language differences).

In the case of domestic knowledge diffusion, Griliches (1957) showed for the US that the adoption of hybrid corn was gradual, and that the cumulative adoption process followed a logistic or S-function. Griliches' work spawned a number of studies that also found S-shaped patterns in other technology diffusion processes. This implies that it might take a long time until most firms adopt the new technology. For instance, Greenwood (1997) found that it took 54 years for the rate of adoption to rise from 10% to 90% of existing firms for steam locomotives and 25 years for diesels in the US, and Manuelli and Seshadri (2003) found it took 35 years for tractors.<sup>1</sup>

This paper is concerned with the process of international rather than intranational technology diffusion. Keller (2002a) shows for international knowledge diffusion that the effect of R&D performed in the G-5 countries on productivity in smaller OECD countries declines with distance, i.e., international technology diffusion is costly and its cost rises with distance.

The studies described above imply that access to knowledge is not instantaneous. Rather, its rate of adoption is subject to the usual cost-benefit considerations and typically leads to gradual adoption. Consequently, knowledge accumulation will occur through an increase in quantity (increased diffusion of existing knowledge), an increase in quality (new knowledge), or both.

In an international context, trade-related knowledge diffusion can occur through an increase in a country's level of exposure to that knowledge through trade (quantity), through an increase in the knowledge-content of that trade (quality), or both. This paper

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<sup>1</sup> Gradual adoption is typically attributed to some market imperfection, including lobbying (Parente and Prescott 1994), imperfect information (Jovanovic and MacDonald 1994) or learning by doing (Jovanovic and Lach 1989; Jovanovic and Nyarko 1996). Manuelli and Seshadri (2003) obtain the same diffusion pattern for tractors in a frictionless model, with gradual adoption due to the change in exogenous variables over time, including labor costs.

investigates how these two components of knowledge diffusion affect productivity. Given the higher cost of international relative to domestic knowledge diffusion, examining the differential impact of the quantity and quality of knowledge diffusion in an international context seems particularly promising.

A recent literature has examined the impact of trade on knowledge diffusion by constructing measures of access to foreign knowledge and estimating the latter's effect on productivity.<sup>2</sup> The seminal paper is Coe and Helpman (1995). It estimates the impact on total factor productivity (TFP) of "foreign R&D," where foreign R&D is defined as the sum of trading partners' R&D stocks (i.e., a measure of knowledge quality), weighted by the bilateral trade shares (a measure of knowledge quantity). Using aggregate data, Coe and Helpman (1995) and Lumenga-Neso et al. (2001) find for developed countries and Coe et al. (1997) for developing countries that foreign R&D has a significantly positive impact on TFP. Thus, TFP rises with the degree of a country's openness and with the trading partners' R&D stocks. Similar findings are obtained at the industry level by Keller (2002b) for developed countries and by Schiff et al. (2002) for developing countries.

These papers treat the two components of trade-related knowledge diffusion—i.e., openness and trading partners' R&D stocks—symmetrically in their empirical analysis. This paper subjects the symmetry assumption to rigorous testing and concludes that the impact of the two components is asymmetric. Openness plays a more (less) important role than trading partners' R&D stocks in North-South (North-North) knowledge

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<sup>2</sup> Recent interest in the relationship between trade and growth and in international technology spillovers is based on the development of endogenous growth theories (e.g., Romer 1986, 1990) and their application to the open economy case (Grossman and Helpman 1991).

diffusion and has a greater (smaller) impact on productivity in the South (North) than found in the existing literature.

The paper is organized as follows. Section 2 sets forth a brief analytical framework. Section 3 deals with North-North trade. Section 3.1 presents the empirical implementation, Section 3.2 provides the empirical results, and Section 3.3 compares them with those in the literature. Section 4 does the same for North-South trade, and Section 5 concludes.

## 2. Analytical Framework

This paper investigates the relative contributions to a developed or developing country's TFP of the R&D performed in OECD countries (quality of knowledge) and of the degree of access to this knowledge through trade (quantity of knowledge). Total factor productivity TFP is assumed to be given by:

$$TFP = TFP(T, Z), \quad (1)$$

where  $T$  denotes technological knowledge, and  $Z$  is a vector of other factors affecting TFP including, for instance, education. Technological knowledge  $T$  in a given country is assumed to be given by

$$T = T(RD, NRD); \quad T_1, T_2 > 0, \quad (2)$$

where  $RD$  is the stock of R&D produced in that country,  $NRD$  is the access to the trading partners' R&D stocks, and  $T_1$  and  $T_2$  are the first order derivatives with respect to  $RD$  and  $NRD$ , respectively. Access to the foreign stock of R&D,  $NRD$ , is assumed to be given by

$$NRD = NRD(OPEN, RDC); \quad NRD_1, NRD_2 > 0, NRD_{11} < 0. \quad (3)$$

Thus,  $NRD$ , the level of access to trading partners' R&D stocks, is a function of  $OPEN$ , the degree of a country's openness, and  $RDC$ , a measure of trading partners' R&D stocks (i.e., a measure of the R&D content of the country's trade).<sup>3</sup> The second derivative  $NRD_{11}$  is assumed to be negative to reflect the fact that the additional knowledge a country obtains from the imports of a given machine is likely to diminish with the number of units of that machine that it imports.

Past studies that have examined trade-related technology diffusion have assumed that openness and trading partners' R&D stocks enter symmetrically in  $NRD$ , i.e., that equation (3) takes the form:

$$NRD = NRD(OPEN * RDC) \quad (4)$$

and that equation (1) takes the form:

$$TFP = TFP(T(RD, OPEN * RDC), Z). \quad (5)$$

This paper investigates whether the variables  $OPEN$  and  $RDC$  actually enter symmetrically in the TFP equation. We test this hypothesis both for North-North trade (among OECD countries) and for North-South trade (between OECD and developing countries).

### 3. North-North Trade

#### 3.1. Empirical Implementation

For North-North trade, we use the same aggregate data as that used by Coe and Helpman (1995) and Keller (1998). The data set consists of 22 developed countries (21 OECD countries and Israel) and 20 years (1971-1990). The reason for using aggregate

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<sup>3</sup>  $NRD$  is what is referred in the literature as "foreign R&D."

data is that it allows a more precise comparison of our results with those of Coe and Helpman (1995), the seminal paper in this literature, and Keller (1998). Another reason is that a third of our sample of OECD countries does not report R&D data at the industry level, with data available only for 15 countries.<sup>4</sup>

Coe and Helpman (1995) define  $NRD$  as the sum over all trading partners of their R&D stocks multiplied by the trade shares. They define trade shares as the imports from trading partners divided by the sum of these imports. The fact that the trade shares add up to one implies that the level of total imports does not affect  $NRD$  (as long as the shares are unchanged).<sup>5</sup> In this paper, trade shares are defined relative to GDP, and the level of imports does affect  $NRD$ . Thus,  $NRD$  for country  $c$  is given by:

$$NRD_c \equiv \sum_{k \neq c} \left( \frac{M_{ck}}{GDP_c} \right) RD_k, \quad (6)$$

where  $M$  is imports,  $RD$  is the stock of R&D, and  $k$  stands for the trading partner countries.

We define two transformations of  $NRD$ , one that measures openness, and the other that measures the R&D content of imports. Openness is defined as

$$OPEN_c \equiv \sum_{k \neq c} \frac{M_{ck}}{GDP_c}, \quad (7)$$

which is obtained by setting  $RD_k = 1, \forall k$ , in equation (6). The R&D content of trade,  $RDC$ , is defined as

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<sup>4</sup> And another reason is the failure of producing reasonable empirical results at the industry level for G7 countries plus Sweden. We selected these countries to compare our results with those of Keller (2002b) who examines the impact of domestic R&D and trading partners' R&D (i.e.,  $RDC$ ), but not of openness. Keller (2002b) covers data from 1970 to 1991. We had to restrict our sample because industry-level trade data are only available from 1976. We do not report the results because, even though  $NRD$  was positive and significant, the domestic R&D variable was never significant in the restricted sample.

<sup>5</sup> Coe and Helpman (1995) do add the share of imports in GDP in their third TFP regression, though in a different way than trade shares and R&D stocks (see Lumenga-Neso et al. 2001 for more details).



$$RDC_c \equiv \sum_{k \neq c} RD_k, \quad (8)$$

which is obtained by setting  $M_{ck} / GDP_c = 1, \forall c, k$ , in equation (6).

Two alternative equations are estimated:

$$\begin{aligned} \log TFP_{ct} = & \beta_0 + \beta_1 \log RD_{ct} + \beta_N \log NRD_{ct} + \beta_T \log OPEN_{ct} \\ & + \sum_t \beta_t D_t + \sum_c \beta_c D_c + \varepsilon_{ct}, \end{aligned} \quad (9)$$

and

$$\begin{aligned} \log TFP_{ct} = & \beta'_0 + \beta'_1 \log RD_{ct} + \beta'_N \log NRD_{ct} + \beta'_R \log RDC_{ct} \\ & + \sum_t \beta'_t D_t + \sum_c \beta'_c D_c + \varepsilon'_{ct}, \end{aligned} \quad (10)$$

where  $NRD$ ,  $OPEN$  and  $RDC$  are defined in equations (6), (7) and (8),  $RD_c$  is the home-country's stock of R&D, and  $D_t$  ( $D_c$ ) are time (country) dummies.

Assume that when imports or the R&D content of imports change, the proportional change is the same across all trading partners. Then, in equation (9), the elasticity of TFP with respect to openness is  $\beta_N + \beta_T$  and the elasticity with respect to the R&D content of trade is  $\beta_N$ . In equation (10), the elasticity of TFP with respect to openness is  $\beta'_N$  and with respect to the R&D content of trade is  $\beta'_N + \beta'_R$ . If openness and the R&D content of trade enter symmetrically in TFP (as they do in the variable  $NRD$  (equation 6)), we should obtain  $\beta_T = 0$  in equation (9),  $\beta'_R = 0$  equation (10), and  $\beta_N = \beta'_N$ . On the other hand, if the impact of openness on TFP is larger (smaller) than the impact of the R&D content, we should obtain  $\beta_T > (<) 0$  and  $\beta'_R < (>) 0$ .

Note that the value of these coefficients is likely to depend on the level of development of the importing country. In OECD countries where communication and

information systems are more highly developed, new knowledge is likely to spread more rapidly and the marginal impact of additional imports is likely to be smaller. On the other hand, less developed communication and information systems in developing countries implies that knowledge is likely to spread less rapidly, and the marginal impact of additional imports is likely to be bigger.

### 3.2. Empirical Results

Before turning to the econometric analysis, we need to consider the issue that two or more variables may be trended and contain unit roots, making the regression results spurious (unless the variables are co-integrated). As noted earlier, we use the same data as Coe and Helpman (1995). They find that their variables exhibit a clear trend but are co-integrated, justifying the estimation of a relationship in the levels of the variables without having to adjust them.

The empirical results are presented in Table 1. Results for time and country dummies are not shown. Regression (i) indicates that the elasticities of both RD (own R&D stock) and NRD are positive and significant at the 1% level, with the former over twice as large as the latter (.112 versus .045). Regression (ii) adds the variable OPEN to those of RD and NRD. The elasticities with respect to RD (.119) and NRD (.055) are similar to those in regression (i), and the elasticity with respect to OPEN is -.071 (all significant at the 1% level). This implies that the elasticity with respect to the R&D content of trade is  $\beta_N = .055$  and that with respect to openness is  $\beta_N + \beta_T = -.016$  and not significantly different from zero. These results imply that symmetry is rejected and

that the R&D content of trade (the quality of trade) has a greater impact on TFP than the degree of openness (the quantity of trade).

In regression (iii),  $\beta'_N = -.004$  (not significant) and  $\beta'_R = .208$  (significant at the 1% level). Thus, the elasticity of TFP with respect to openness is  $\beta'_N = -.004$  (not significant) and that with respect to the R&D content of trade is  $\beta'_N + \beta'_R = .204$ . Though the elasticities in regression (iii) differ from those in regression (ii), the qualitative result is the same: symmetry is rejected, and the R&D content of trade has a greater impact on TFP than the degree of openness.<sup>6</sup>

Why does the R&D content of trade have a greater impact on TFP than the degree of openness? First, most OECD countries have low trade barriers and openness is typically high. Consequently, the marginal impact of trade is likely to be small ( $NRD_{11} < 0$  in equation (3)). Second, alternative means of diffusing knowledge are available, including FDI, licensing, the internet and other telecommunications technology, as well as scientific journals and international meetings. These reduce the importance of trade as a means of knowledge diffusion.

Note that conditions with respect to openness and other channels of technology diffusion differ greatly in the South. Over our estimation period 1976-1998, tariffs averaged 6.3% for the 15 sample OECD countries and 20.5% or over three times more in the 24 sample developing countries. As for alternative channels of technology diffusion, internet users over the period 1990-1998 averaged 52.8 per thousand people in the 15 sample OECD countries and 6.8 or about eight times less in the 24 sample developing

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<sup>6</sup> We did estimate TFP as a function of *NRD*, *OPEN* and *RDC* but did not obtain satisfactory results because of multi-collinearity problems between these variables.

countries; and FDI averaged US\$ 95.6 billion over the period 1976-1998 for the 15 OECD countries and US\$ 33.8 billion or about a third from the 15 OECD countries to *all* developing countries. Unsurprisingly, as shown in Section 4, the empirical results differ for North-South trade as compared to North-North trade.

### 3.3. Comparison with the Literature

In their seminal paper, Coe and Helpman (1995) estimate regression (i) and obtain an elasticity of TFP with respect to *NRD* of .092, and of .060 when they add a dummy variable to capture the additional effect of domestic R&D in the G-7 countries.<sup>7</sup> In a much cited paper, Keller (1998) uses the same data as Coe and Helpman and estimates alternative versions of TFP equations. In one specification, he regresses TFP on *RD* and *RDC*, with results that are as good or better than those of Coe and Helpman. He obtains an elasticity of TFP with respect to *RDC* of .161, and of .129 when the dummy variable is added to capture the additional effect of domestic R&D in the G-7 countries. He concludes that a country's trading partners' R&D does not necessarily diffuse through trade, and that nontrade channels should be investigated as well.

Keller's point seems well taken. His results are close to those in regression (iii), though our interpretation differs somewhat from his. By incorporating both *NRD* and *RDC* (in addition to *RD*) in regression (iii), we allow the data to determine which of the two effects is dominant, openness or trading partners' R&D stocks. Our interpretation is

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<sup>7</sup> As mentioned in Section 3.1, the trade shares used in the definition of *NRD* in the first two equations estimated by Coe and Helpman (C-H) differ from ours. In C-H, these shares add up to one, and the effect of an overall increase in openness cannot be simulated. For given shares, the elasticity of TFP with respect to *NRD* reflects the impact of an equi-proportionate increase in trading partners' R&D stocks. Thus, their results are not so far from ours. C-H do include a measure of openness in a third regression by multiplying it by log *NRD*. However, they model a log-log relationship with respect to *NRD* but a semi-log relationship with respect to openness.

that the effect of trading partners' R&D stocks on TFP is dominant in North-North trade, but that this reflects both the influence of nontrade channels as well as the fact that OECD economies are typically very open so that the marginal effect of openness is small.

This result does not generalize to North-South trade due to the different conditions in the South described above. As is shown in Section 4, opposite findings are obtained for North-South trade, with openness having a significant impact on TFP.

#### 4. North-South Trade

##### 4.1. Empirical Implementation

For North-South trade, we make use of a data set of industry-level trade-related technology diffusion used in Schiff et al. (2002). The data set consists of 16 manufacturing industries, 24 developing countries, 15 OECD trading partners, and 22 years (from 1977 to 1998). The 16 industries are further divided into high and low R&D-intensity groups (with R&D intensity defined as the ratio of expenditures on R&D to value added). The average R&D intensity is 1.3% for the “low” group and 11% for the “high” group. High R&D intensity industries are shown in italics in footnote 8.<sup>8 9 10 11</sup> As in Coe et al. (1997), domestic R&D was not included due to the lack of data.

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<sup>8</sup> The 16 manufacturing industries are: 31-Food, Beverage & Tobacco; 32-Textiles, Apparel & Leather; 33-Wood Products & Furniture; 34-Paper, Paper Products & Printing; 351/2-Chemicals, Drugs & Medicines; 353/4-Petroleum Refineries & Products; 355/6-Rubber & Plastic Products; 36-Non-Metallic Mineral Products; 371-Iron & Steel; 372-Non-Ferrous Metals; 381-Metal Products; 382-Non-Electrical Machinery, Office & Computing Machinery; 383-Electrical Machinery and Communication Equipment; 384-Transportation Equipment; and 385-Professional Goods; and 39-Other Manufacturing.

<sup>9</sup> For the “high” group, the average R&D intensity *minus* two standard deviations is 3.8%, which is larger than the average *plus* two standard deviations of the “low” group or 3.1%. Assuming a normal distribution, the hypothesis that any of the industries in the “high” R&D intensity cluster belongs to the “low” cluster is rejected at the 1% significance level.

<sup>10</sup> The 25 developing countries are: Bangladesh, Bolivia, Chile, Cameroon, Colombia, Cyprus, Ecuador, Egypt Arab Rep., Guatemala, Hong Kong- China, Indonesia, India, Iran Islamic Rep., Jordan, Korea Rep., Kuwait, Mexico, Malawi, Malaysia, Pakistan, Philippines, Poland, Trinidad and Tobago, Venezuela.

Schiff et al. (2002) define North-foreign R&D (i.e., knowledge obtained through trade) in industry  $i$  of developing country  $c$ ,  $NRD_{ci}$ , as:

$$NRD_{ci} \equiv \sum_j a_{cij} RD_{cj} = \sum_j a_{cij} \left[ \sum_k \left( \frac{M_{cjk}}{VA_{cj}} \right) RD_{jk} \right], \quad (11)$$

where  $c$  ( $k$ ) indexes developing (OECD) countries,  $j$  indexes industries,  $M$  ( $VA$ ) ( $RD$ ) denotes imports (value added) (R&D), and  $a_{cij}$  is the import input-output coefficient (which measures for country  $c$  the share of imports of industry  $j$  that is sold to industry  $i$ ).

The first part of equation (11) says that, in developing country  $c$ , North-foreign R&D in industry  $i$ ,  $NRD_{ci}$ , is the sum, over all industries  $j$ , of  $RD_{cj}$ , the industry- $j$  foreign R&D obtained through imports, multiplied by  $a_{cij}$ , the share of imports of industry  $j$  that is sold to industry  $i$ . The second part of equation (11) says that  $RD_{cj}$  is the sum, over OECD countries  $k$ , of  $M_{cjk}/VA_{cj}$ , the imports of industry- $j$  products from OECD country  $k$  per unit of industry- $j$  value added (i.e., the bilateral openness share), multiplied by  $RD_{jk}$ , the stock of industry- $j$  R&D in OECD country  $k$ .

We define an openness variable as:

$$OPEN_{ci} = \sum_j a_{cij} \left[ \sum_k \left( \frac{M_{cjk}}{VA_{cj}} \right) \right] \quad (12)$$

which is derived from equation (11) by setting  $RD_{jk} = 1, \forall j, k$ .

Second, we define an R&D variable

$$RDC_{ci} = \sum_j a_{cij} \left[ \sum_k RD_{jk} \right] \quad (13)$$

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<sup>11</sup> The 15 OECD countries are: Australia, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom, and United States.

which is derived from equation (11) by setting  $M_{cjk}/VA_{cj} = 1, \forall c, j, k$ .

As in Coe et al. (1997), Schiff et al. (2002) and others, education is included in the regression as a control variable. Two alternative equations are estimated:

$$\begin{aligned} \log TFP_{cit} = & \beta_0 + \beta_N \log NRD_{cit} + \beta_T \log OPEN_{cit} + \beta_E E_{ct} \\ & + \sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit}, \end{aligned} \quad (14)$$

and

$$\begin{aligned} \log TFP_{cit} = & \beta'_0 + \beta'_N \log NRD_{cit} + \beta'_L \log RDC_{cit} + \beta'_E E_{ct} \\ & + \sum_t \beta'_t D_t + \sum_c \beta'_c D_c + \sum_i \beta'_i D_i + \varepsilon'_{cit}, \end{aligned} \quad (15)$$

where  $E$  denotes education, and  $D_t$  ( $D_c$ ) ( $D_i$ ) represents time (country) (industry) dummies. The effects for high and low R&D intensity industries are estimated by introducing a dummy variable,  $DR$ , with  $DR = 1$  for high R&D-intensity industries and  $DR = 0$  otherwise.

#### 4.2. Empirical Results

As with the analysis of North-North trade, we need to consider the possibility that two or more variables might be trended and contain unit roots, making the regression results spurious (unless the variables are co-integrated). The unit root hypothesis was rejected at the 1% significance level for  $\log TFP$ ,  $\log NRD$ ,  $\log OPEN$  and  $\log RDC$ .<sup>12</sup>

The estimation results are presented in Table 2. The education variable  $E$  is significant at the 1% level in all six regressions, with a one percentage point increase in education raising TFP by between 6.8 and 7.5 percent.

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<sup>12</sup> Test results are available from the authors on request.

Regressions (i) and (ii) are reproduced from Schiff et al. (2002). They impose symmetric effects of openness and R&D on TFP. Regression (i) shows a positive impact of *NRD* on TFP (significant at the 1% level), with an elasticity of about .19. Regression (ii) distinguishes between low and high R&D-intensity industries, and shows an elasticity of about .14 for low R&D-intensity industries and of .28 for high R&D-intensity industries, both significant at the 1% level. As might be expected, foreign R&D has a greater impact on the productivity of R&D-intensive industries.

Columns (iii) and (iv) regress TFP on *NRD* and *OPEN* (see equation (14)). Regression (iii) shows that the elasticity of TFP with respect to R&D is  $-.012$  and not significantly different from zero, and the elasticity with respect to openness is about .24 (.251 - .012), significant at the 1% level. Regression (iv) distinguishes between low and high R&D-intensity industries. For low R&D-intensity industries, the elasticity of TFP with respect to R&D is  $-.065$  and not significantly different from zero, and the elasticity with respect to openness is .23 (.295 - .065), significant at the 1% level. For high R&D-intensity industries, the elasticity of TFP with respect to R&D is .22 (.285 - .065), significant at the 1% level, and the elasticity with respect to openness is about .27 (.22 + .295 - .244).

The results from regression (iv) imply that R&D has no impact on the TFP of low R&D-intensity industries and has a significant impact on the TFP of high R&D-intensity industries. Second, openness has a significant impact on the TFP of both low and high R&D-intensity industries. The impact of openness is larger than that of R&D, significantly so for low R&D-intensity industries and somewhat less so for high R&D-intensity industries. The results on the importance of R&D are quite plausible. One would



expect the embodied technology or R&D content of imports to matter more in industries where technology plays a more important role, i.e., in R&D-intensive industries.<sup>13</sup>

Columns (v) and (vi) correspond to equation (15). Regression (v) shows an elasticity of TFP with respect to openness equal to about .37 (significantly different from zero at the 1% level) and with respect to R&D not significantly different from zero (-.039). These results confirm those of regression (iii).

Regression (vi) shows an elasticity of TFP with respect to openness equal to about .29 for low R&D-intensity industries and of .45 for high R&D-intensity industries, both significant at the 1% level. The elasticity of TFP with respect to R&D is not significantly different from zero for low R&D-intensity industries ( $.046 = .294 - .248$ ) or for high R&D-intensity industries ( $.013 = .046 + .156 - .189$ ). These results confirm those of regression (iv), though the elasticities with respect to openness in both industry groups are larger in this case and the elasticity with respect to R&D in high R&D-intensity industries is smaller.

#### 4.3. Comparison with the literature

The results obtained here imply that the impact of openness on TFP in developing countries is greater than that obtained in Schiff et al. (2002) where the effects of openness and R&D were constrained to be symmetric. For all industries taken together, the elasticity of TFP with respect to openness is .19 in the case of symmetry and is between .24 and .37 in the absence of symmetry. When industries are split between high and low R&D-intensity industries, the elasticity of TFP with respect to openness is .14 for low

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<sup>13</sup> For low R&D-intensity industries, only openness matters. This result could at least partly reflect the fact that greater openness has a disciplining effect by increasing the level of contestability and competitiveness of the domestic industry.

R&D-intensity industries in the case of symmetry, and between .23 and .29 in the unconstrained case. For high R&D-intensity industries, the elasticity is .28 under symmetry, and is between .27 and .45 in the unconstrained case. Thus, the openness elasticity for the low R&D-intensity industries is between 60 and 100 percent larger than when symmetry between the R&D and openness effects is imposed, and between 0 and 60 percent larger for the high R&D-intensity industries.

As noted earlier, Coe et al. (1997) estimate the impact of North-South R&D spillovers at the aggregate level. They tried a variety of specifications, including some with an openness variable. In their preferred specification, they obtain an elasticity of TFP with respect to NRD of .058 and an elasticity of TFP with respect to the share of imports to GDP (openness) of .279, both significant at the 1% level.<sup>14</sup> The sum of weights for NRD in Coe et al. (1997) is one, so the elasticity of TFP with respect to R&D is .058 and with respect to openness is .279. Coe et al. (1997) estimate a total of 10 different specifications. The average value of the elasticity of TFP with respect to NRD is negative and with respect to openness is .304. These results support our findings that the elasticity of TFP with respect to openness is larger than that with respect to R&D, and the values obtained fall within the range of our estimates.

Finally, the conclusions of both Falvey et al. (2002) and Keller (2000) lend support to our results. Falvey et al. (2002) estimate North-South R&D spillovers at the aggregate level and use various definitions of NRD, including that of Coe and Helpman (1995) and that of Lichtenberg and van Pottelsberghe de la Potterie (1998). They conclude that only the specifications that include the level of imports result in positive coefficients for the effect of knowledge spillovers. Finally, Keller (2000) concludes that

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<sup>14</sup> Coe et al. (1997) use imports of machinery and equipment rather than total imports.

openness should play a greater role for technology diffusion and productivity growth in developing countries than in developed ones.

## 5. Conclusion

A recent literature has examined the impact of trade-related technology diffusion on productivity (TFP). That literature imposed symmetry between the impact of openness and that of the R&D content of trade. This paper examines this issue in the context of North-North and North-South technology diffusion, and shows that the assumption of symmetry is not warranted in either case. The main findings are as follows.

For North-North trade:

- i) The R&D content of trade has a greater impact on TFP than openness.
- ii) While studies imposing symmetry between the TFP effects of the R&D content of trade and openness find a positive impact of openness, our analysis indicates that the effect of openness on TFP is not significantly different from zero.

For North-South trade:

- i) Openness has a greater impact on TFP than the R&D content of trade.
- ii) The impact of openness on TFP is greater than is obtained when symmetry is imposed.
- iii) The impact of the R&D content of trade on TFP is not significantly different from zero in low R&D-intensity industries and may be positive in R&D-intensive industries.

These results imply that the gains from trade liberalization in developing countries are likely to be larger than was previously obtained in the literature.

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Table 1. Determinants of TFP in OECD Countries

	(i)	(ii)	(iii)
<b>logRD</b>	<b>.112</b> <b>(14.1)***</b>	<b>.119</b> <b>(14.77)***</b>	<b>0.045</b> <b>(4.25)***</b>
<b>logNRD</b>	<b>0.045</b> <b>(4.9)***</b>	<b>0.055</b> <b>(5.82)***</b>	<b>-0.004</b> <b>(-0.43)</b>
<b>logOPEN</b>		<b>-0.071</b> <b>(-3.67)***</b>	
<b>logRDC</b>			<b>0.208</b> <b>(8.63)***</b>
<b>Adj. R<sup>2</sup></b>	<b>0.60</b>	<b>0.61</b>	<b>0.66</b>
<b>Observations</b>	<b>440</b>	<b>440</b>	<b>440</b>

Note: Figures in parenthesis are t-statistics. Results on country dummies are not reported. DRD is domestic R&D stock, NRD is the trade-related foreign R&D stock defined in eq. (6), OPEN is the ratio of a country's total imports over its GDP, and RDC is the sum of the R&D stock for the rest of the sample.

Table 2. Determinants of TFP in Developing Countries

Variables	(i)	(ii)	(iii)	(iv)	(v)	(vi)
logNRD	<b>0.188</b> (6.11)***	<b>0.138</b> (4.03)***	<b>-0.012</b> (-0.19)	<b>-0.065</b> (-0.99)	<b>0.369</b> (8.82)***	<b>0.294</b> (6.31)***
logNRD*DR		<b>0.141</b> (3.52)***		<b>0.285</b> (4.02)***		<b>0.156</b> (3.5)***
logOPEN			<b>.251</b> (3.89)***	<b>0.295</b> (4.23)***		
logOPEN*DR				<b>-0.244</b> (-3.13)***		
logRDC					<b>-0.408</b> (-6.38)***	<b>-0.248</b> (-3.89)***
logRDC*DR						<b>-0.189</b> (-2.15)**
E	<b>6.831</b> (4.34)***	<b>6.823</b> (4.34)***	<b>6.9</b> (4.37)***	<b>6.866</b> (4.37)***	<b>7.462</b> (4.74)***	<b>7.411</b> (4.72)***
Adjusted R <sup>2</sup>	<b>0.23</b>	<b>0.23</b>	<b>0.23</b>	<b>0.24</b>	<b>0.24</b>	<b>0.24</b>
No. of Observations	<b>5721</b>	<b>5721</b>	<b>5721</b>	<b>5721</b>	<b>5721</b>	<b>5721</b>

Note: Figures in parentheses are t-statistics. Significance levels of 1%, 5% and 10% are indicated by \*\*\*, \*\* and \* respectively. Regression results on country, year and industry dummies, and the constant, are not reported. NRD is the trade-related North-foreign R&D defined in equation (11), OPEN is defined in equation (12) and RDC in equation (13). E is the secondary school completion ratio for the population aged 25 and above. DR = 1 for R&D-intensive industries and DR= 0 for low R&D-intensive industries.